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Recent Advances in Josephson Device and Material

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Josephson junctions have received much attention in the field of computer applications in recent years because of their fast switching speeds and very low power dissipations. Josephson devices are based on superconductivity and must be operated at very low temperature of about 4 K. The low temperature operation and the use of superconductivity provide the unique properties of Josephson devices in contrast to existing semiconductor devices. However, the low temperature operation and the different principle of operation make Josephson technologies incompatible with the room temperature semiconductor technologies. This means that almost all of the technologies should be newly developed and a large amount of effort will be needed to realize Josephson systems, although a significant progress in Josephson technologies has been done at IBM Research Laboratories and, recently, various institutes in Japan. This paper discusses new approaches in Josephson logic devices and materials, which would overcome bottlenecks in the existing Josephson technologies.

Devices

Josephson logic devices can be classified into two different types; one is the magnetic coupled type, in which the gate structure is based on an interferometer, and the other is a direct-coupled type controlled by direct injection of current into the gate.

The interferometer logic devices have been developed notably at IBM as CIL (Current Injection Logic) family.[1] The interferometer logic has an advantage that the input/output current isolation is completely achieved, which is quite useful to build complicated circuits. However, the interferometer uses an inductance loop which makes the device size and the logic delay relatively large.

The direct-coupled type logic devices, on the other hand, are essentially inductance-free so that the smaller device size and the faster logic delay can be expected, provided the input/output current isolation is completely performed.

We have proposed a new direct-coupled logic gate in which four Josephson junctions are closely coupled in a loop.[2] In this four junction logic (4JL) gate, inductances can be eliminated from the gate so that the operating characteristics are determined by only junction chataceristics, which gives a potential advantage for designing the gate. Another important feature of the 4JL gate is that the current isolation can be easily achieved by connecting a small resistor to the input terminal. Gate operations under the complete current isolation have been performed with the gate delay of less than 20 ps and a power dissipation of 3.7 μW for devices fabricated with a 5 μm technology.[3] Detailed operating characteristics, the logic family, the basic logic circuits and the system considerations of the 4JL gate will be discussed in the paper.

Materials

In order to realize the Josephson computer system, it is important to develop Josephson LSI technology. At the present stage, Pb alloy technology is available for integrating Josephson junctions. Although a significant improvement has been made, Pb alloy technology still has problems in junction stability, reliability, and uniformity, because the materials are mechanically soft and the grain size of the film is relatively large.

Refractory superconducting materials such as Nb and its compounds are mechanically hard and high T_c's; these properties are quite attractive for fabricating tunnel junctions with high stability or reliability for thermal cycling and storage.

We have been studying an integration technology in which NbN films are used as electrodes.[4,5] NbN has excellent properties for fabricating Josephson tunnel junctions. The surface of NbN film is less chemically active than that of Nb, which makes it possible to control tunnel barriers precisely. Furthermore, NbN has a high superconducting transition temperature of about 15 K, resulting in lowering the subgap leakage current and increasing stability of operation against small tempetature fluctuations. We have developed a new integration process for all hard Josephson junctions based on NbN, Nb double layered electrodes, in which a reactive ion etching is introduced for patterning electrodes, and all junction structure is simultaneously made in a sputtering chamber without breaking vacuum. The fabricated junctions show excellent tunneling characteristics with low subgap leakage and uniformity of less than 5 % in 100 series-connected 2.5 μm junctions at current densities of more than 10^4 A/cm^2. These results indicate that all hard refractory junctions may be almost at practical use.

References

1) T. R. Gheewala: IBM J. Res. Dev. 24, 130 (1980).
2) S. Takada et al.: Jpn. J. Appl. Phys. Suppl.19, 607 (1980).
3) H. Nakagawa et al.: Jpn. J. Appl. Phys. Lett. 21 No. 4 (1982).
4) F. Shinoki et al.: Appl. Phys. Lett. 38, 314 (1981).
5) A. Shoji et al.: Jpn. J. Appl. Phys. Lett. 21, No. 4 (1982).